1.GS:
Rpi 52
c. 2

George M Wilson

STATE OF ILLINOIS
HENRY HORNER, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
JOHN J. HALLIHAN, *Director*

DIVISION OF THE
STATE GEOLOGICAL SURVEY
M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS—NO. 52

# PETROLOGY OF THE PENNSYLVANIAN UNDERCLAYS OF ILLINOIS

BY
RALPH E. GRIM AND VICTOR T. ALLEN

REPRINTED FROM THE BULLETIN,
GEOLOGICAL SOCIETY OF AMERICA,
VOL. 49, PP. 1485-1514, 1938.

ILLINOIS GEOLOGICAL
SURVEY LIBRARY
JUL 30 1975

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS
1938

STATE OF ILLINOIS
HON. HENRY HORNER, *Governor*
DEPARTMENT OF REGISTRATION AND EDUCATION
HON. JOHN J. HALLIHAN, *Director*

BOARD OF
NATURAL RESOURCES AND CONSERVATION
HON. JOHN J. HALLIHAN, *Chairman*

EDSON S. BASTIN, Ph.D., *Geology*
WILLIAM A. NOYES, Ph.D., LL.D., Chem.D., D.Sc., *Chemistry*
LOUIS R. HOWSON, C.E., *Engineering*
WILLIAM TRELEASE, D.Sc., LL.D., *Biology*
HENRY C. COWLES, Ph.D., D.Sc., *Forestry*
ARTHUR CUTTS WILLARD, D.Engr., LL.D., *President of the University of Illinois*

STATE GEOLOGICAL SURVEY DIVISION
*Urbana*
M. M. LEIGHTON, Ph.D., *Chief*
ENID TOWNLEY, M.S., *Assistant to the Chief*
JANE TITCOMB, M.A., *Geological Assistant*

GEOLOGICAL RESOURCES

*Coal*
G. H. CADY, Ph.D., *Senior Geologist*
L. C. MCCABE, Ph.D.
JAMES M. SCHOPF, Ph.D.
EARLE F. TAYLOR, M.S.
CHARLES C. BOLEY, M.S.

*Non-Fuels*
J. E. LAMAR, B.S.
H. B. WILLMAN, Ph.D.
ROBERT M. GROGAN, M.S.
H. C. HEILBRONNER, B.S.

*Oil and Gas*
A. H. BELL, Ph.D.
CHALMER L. COOPER, M.S.
G. V. COHEE, Ph.D.
FREDERICK SQUIRES, B.S.
CHARLES W. CARTER, Ph.D.
JAMES L. CARLTON, B.S.

*Areal and Engineering Geology*
GEORGE E. EKBLAW, Ph.D.
RICHARD F. FISHER, B.A.

*Subsurface Geology*
L. E. WORKMAN, M.S.
J. NORMAN PAYNE, Ph.D.
ELWOOD ATHERTON, Ph.D.
GORDON PRESCOTT, B.S.

*Stratigraphy and Paleontology*
J. MARVIN WELLER, Ph.D.

*Petrography*
RALPH E. GRIM, Ph.D.
RICHARDS A. ROWLAND, Ph.D.

*Physics*
R. J. PIERSOL, Ph.D.
M. C. WATSON, Ph.D.
DONALD O. HOLLAND, M.S.

GEOCHEMISTRY

FRANK H. REED, Ph.D., *Chief Chemist*
W. F. BRADLEY, Ph.D.
G. C. FINGER, Ph.D.
VELMA E. NICHOLS, M.S.

*Fuels*
G. R. YOHE, Ph.D.
CARL HARMAN, B.S.

*Non-Fuels*
J. S. MACHIN, Ph.D.
F. V. TOOLEY, M.S.

*Analytical*
O. W. REES, Ph.D.
NORMAN H. NACHTRIEB, B.S.
GEORGE W. LAND, B.Ed.
P. W. HENLINE, B.S.
MATHEW KALINOWSKI, B.S.

MINERAL ECONOMICS

W. H. VOSKUIL, Ph.D., *Mineral Economist*
GRACE N. OLIVER, A.B.

EDUCATIONAL EXTENSION

DON L. CARROLL, B.S.

PUBLICATIONS AND RECORDS

GEORGE E. EKBLAW, Ph.D.
CHALMER L. COOPER, M.S.
DOROTHY ROSE, B.S. *(on leave)*
ALMA R. SWEENEY, A.B.
M. FRANCES HARPER, M.S.
MEREDITH M. CALKINS

Consultants: *Ceramics,* CULLEN WARNER PARMELEE, M.S., D.Sc., University of Illinois; *Pleistocene Invertebrate Paleontology,* FRANK COLLINS BAKER, B.S., University of Illinois.
Topographic Mapping in Cooperation with the United States Geological Survey.
This Report is a Contribution of the Section of Geological Resources, Division of Petrography.

July 1, 1938

ILLINOIS STATE GEOLOGICAL SURVEY
3 3051 00005 6949

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 49. PP. 1485-1514. 2 PLS., 1 FIG. OCTOBER 1, 1938

# PETROLOGY OF THE PENNSYLVANIAN UNDERCLAYS OF ILLINOIS

BY RALPH E. GRIM AND VICTOR T. ALLEN

## CONTENTS

Page

Abstract ..... 1485
Introduction ..... 1486
Lithology and occurrence ..... 1486
Analytical procedure ..... 1489
Mineral analyses ..... 1490
General statement ..... 1490
Lower Pottsville underclays in Goose Lake area, Grundy County ..... 1490
Outcrop characteristics ..... 1490
Mineral composition ..... 1490
Underclay below Coal No. 8 along Salt Fork Creek, Vermilion County ..... 1493
Outcrop characteristics ..... 1493
Mineral composition ..... 1493
Base-exchange capacity determinations ..... 1494
Additional underclays (summary tables) ..... 1495
Textural characteristics ..... 1495
Discussion of analytical results ..... 1500
Previous explanations of origin of underclays ..... 1504
Sedimentary history suggested by mineral composition and texture ..... 1507
Works to which reference is made ..... 1509

## ILLUSTRATIONS

Figure — Page

1. Pennsylvanian outcrop area in Illinois ..... 1488

Plate — Facing page

1. Photomicrographs of underclays ..... 1512
2. Photomicrographs of gumbotils and underclays ..... 1513

## ABSTRACT

The results of a detailed petrologic investigation of underclays of various types occurring beneath the coals in Illinois are presented. The mineral composition of the clay grade was determined by optical, X-ray, and chemical criteria, frequently following sedimentation and supercentrifuge separations into fractions sufficiently simple mineralogically so that the analytical data could be definitely interpreted. Constituents coarser than clay were identified with the petrographic microscope. Base-exchange capacity values and textural characteristics are presented and discussed.

The completely noncalcareous underclays occurring most commonly beneath coal No. 2 and older coals are composed largely of kaolinite. Varying amounts of illite

and quartz are also present. Occasional beds are found in these underclays which are composed almost wholly of a distinctive member of the illite clay mineral group. The calcareous underclays and those grading from noncalcareous to calcareous which occur beneath younger coals contain illite as the essential clay mineral constituent. Except for variations in the calcite and quartz content and a slight concentration of limonite in a zone several inches below the coal, there is no evidence of variation in the mineral constitution or chemical composition within beds of the latter underclays as they are traced downward from the overlying coal. The analytical data definitely indicate no appreciable vertical variation of the completely noncalcareous underclays.

Underclays seemingly have been subjected little or not at all to processes similar to those forming modern soils. The significance of the petrographic data on the origin and genesis of underclays is discussed in detail.

## INTRODUCTION

This report contains the results of researches on the mineral composition and texture of the Pennsylvanian underclays of Illinois and on the significance of these data in understanding their origin. These researches were undertaken as part of the Illinois State Geological Survey's intensive study of the clay resources of Illinois.

Petrographic research on the underclays of Illinois was begun by Allen in 1929 with study of a series of oriented thin sections from increasing depths beneath several coals. A few chemical and X-ray analyses were obtained. A brief summary of some of the results of this work has been published (Allen, 1932). Since 1932 a large number of petrographic analyses have been made by Grim on many additional underclays. Fractionation by sedimentation or supercentrifuging followed by optical, X-ray, and chemical determinations have been used in making most of these analyses. Thin section examinations and base-exchange capacity determinations also have been obtained. The present report includes the results of the later analyses together with the unpublished results of the earlier study. The conclusions for which the writers are jointly responsible are based on all the analytical data.

## LITHOLOGY AND OCCURRENCE

The Pennsylvanian underclays of Illinois, so named because they usually occur directly beneath beds of coal, have distinctive properties. The material is usually gray, occasionally carbonaceous, occasionally calcareous, and varying from nongritty to distinctly sandy. It is particularly distinctive because of the presence of many small, discontinuous, slickensided fracture surfaces along which the clay breaks readily. The slickensided fractures are limited to the clay and are not continuous into overlying or underlying beds. Underclays are generally unbedded and nonlaminated, although occurrences are known in which clay showing a layered character occurs with the underclays or in the position of under-

clay in the cyclothem. Underclays vary in thickness from less than a foot to about 20 feet.

Many underclays contain fresh-water limestone either as continuous beds or as discontinuous nodular masses. The limestone usually has no fossils but at times contains forms indicating a fresh-water or brackish-water environment of accumulation.

The relative position of the underclay with respect to the other sediments of the Pennsylvanian system is shown by the following typical sequence of beds in a Pennsylvanian cyclothem as given by Wanless and Weller (1932) and by Weller (1930).

8. Shale, containing "ironstone" bands in upper part and thin limestone layers in lower part
7. Limestone
6. Calcareous shale
5. Black "fissile" shale
4. Coal
3. Underclay, not uncommonly containing concretionary or bedded fresh-water limestone
2. Sandy and micaceous shale
1. Sandstone

Unconformity

The succession of beds at any particular locality or in any particular cyclothem may be incomplete. Consequently, although underclays are usually immediately overlain by coal, they are occasionally overlain directly by another higher member of the cyclothem or by a member of a succeeding cyclothem. The contact between the underclay and the underlying beds is at times gradational, whereas the contact with the overlying bed is usually sharp. The large areal extent of members of some cyclothems has been emphasized by Wanless and Weller (1932).

The underclays may be grouped into (1) noncalcareous, and (2) calcareous or calcareous grading upward into noncalcareous. Underclays which are noncalcareous throughout are particularly prominent beneath coal No. 2 and older coals. They outcrop in northern, western, and southern Illinois around the margin of the Pennsylvanian outcrop area (Fig. 1). In Grundy and La Salle counties, northern Illinois, underclays of this kind are particularly well known. They are well known also in western Illinois where several noncalcareous underclays beneath the Seahorne limestone constitute the Cheltenham clay horizon near the base of the Pennsylvanian system. The clays are believed by Wanless (1931) to represent several cyclothems, members other than the clays being absent.

With few exceptions underclays beneath coals younger than coal No. 2 are calcareous or calcareous grading upward to noncalcareous. Such

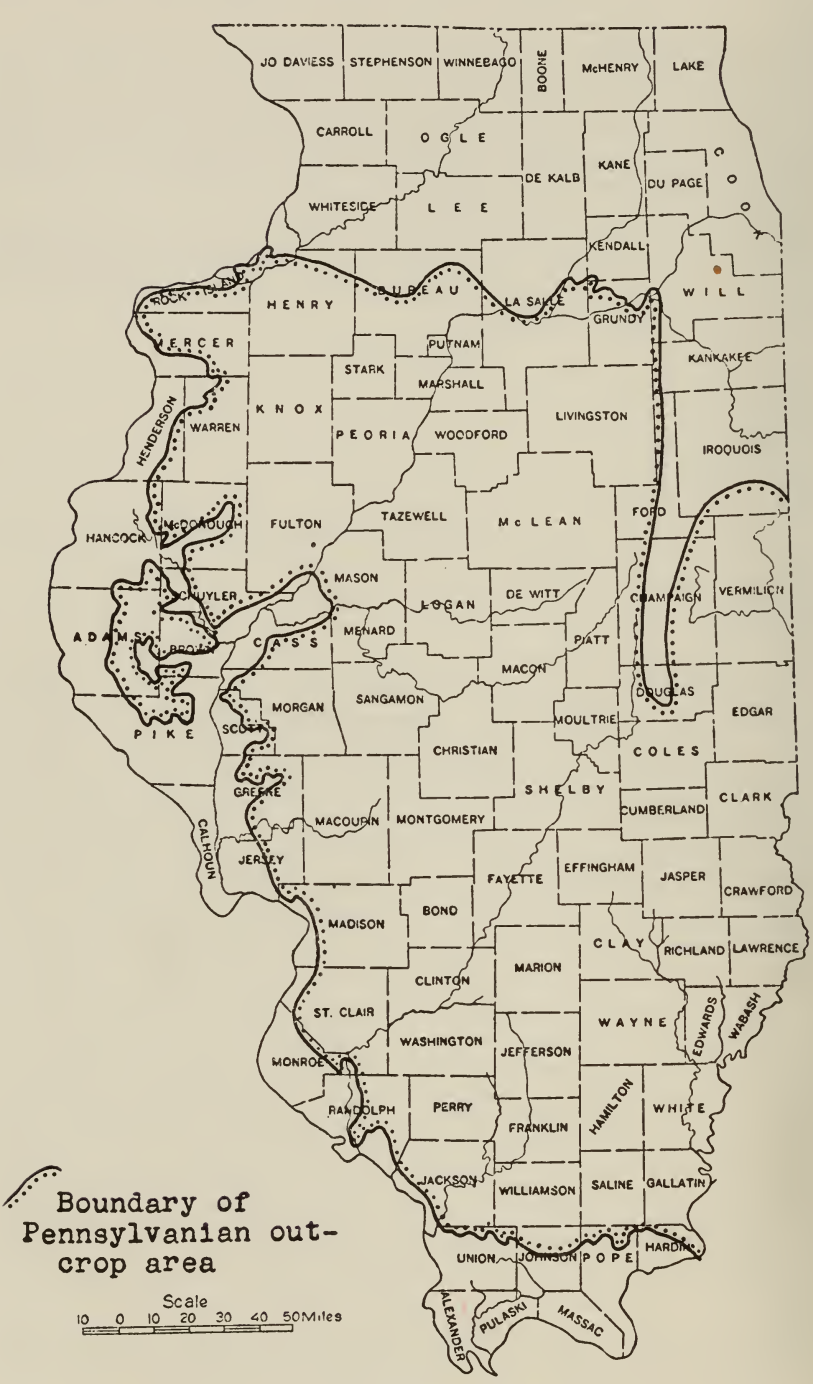



FIGURE 1.—*Pennsylvanian outcrop area in Illinois*

underclays outcrop in the central part of the coal basin in Illinois—in the eastern and central part of the State.

The available subsurface data suggest that the characteristics of the underclays shown at the outcrop are retained when the material is not exposed.

## ANALYTICAL PROCEDURE

Samples were collected from several noncalcareous and calcareous underclays beneath different coals and from the underclay below the same coal in different parts of the State. For each underclay a sequence of samples was obtained representing the material at increasing depths beneath the overlying coal in order to investigate possible changes in constitution downward through the underclay. The intervals between the samples were chosen on the basis of the character of the material as shown in the outcrop. Samples were obtained from each interval that seemed different in any way from overlying or underlying underclay.

Each sample was fractionated by sedimentation methods into Fraction A, which contains all particles smaller than 0.002 mm. and larger particles readily broken down to this size, and Fraction B containing the particles coarser than 0.002 mm. (Grim, 1934). The mineral constituents of Fraction A, which is essentially the clay mineral fraction, were identified on the basis of optical, chemical, and X-ray analytical data.[1] The constituents of Fraction B, which is essentially the non-clay mineral fraction, were identified with the petrographic microscope.

In order to further investigate the finest fractions and to be certain that all the mineral constituents of the colloid fractions were detected, the fractions composed of particles smaller than 0.001 mm. in diameter of several sequences of underclay samples were fractionated by the supercentrifuge, and the constituents were identified by the method described by Bray, Grim and Kerr (1935).

Base-exchange capacity determinations were obtained for a series of samples of one underclay at varying depths beneath the overlying coal. Thin sections were studied for all samples.

Miscellaneous samples from additional underclay horizons were obtained to represent all variations of underclay material that could be found. These samples were studied mainly by thin-section analysis and by separation into fractions A and B followed by mineral identifications. The object in studying them has been to supplement the information obtained from the other samples and thereby to obtain a broader concept of the constitution of all the underclays in Illinois.

[1]X-ray analyses were made on some samples by P. F. Kerr of Columbia University, on others by W. F. Bradley of the Illinois State Geological Survey.

## MINERAL ANALYSES

### GENERAL STATEMENT

Mineral analyses in considerable detail are given for: (1) a series of lower Pottsville underclays from Grundy County, and (2) an underclay of Coal No. 8 from Vermilion County; these are typical examples, respectively, of completely noncalcareous underclay and underclay grading from calcareous to noncalcareous. The analytical data for the samples of additional underclays, which have been studied, are summarized in Tables 5 to 10. Chemical analyses of Fraction A are presented because these data are significant in considering vertical variations in the clay mineral constitution of the underclay.

The megascopic characteristics of all samples are similar to the characteristics of those described in detail. The only differences are in the degree of sandiness, in the presence or absence of calcite, and in the abundance of carbonaceous material and slickensided fracture surfaces.

### LOWER POTTSVILLE UNDERCLAYS IN GOOSE LAKE AREA, GRUNDY COUNTY

*Outcrop Characteristics.*—Three beds of underclay occur in a working clay pit in the Goose Lake area, NW. ¼ NE. ¼ sec. 11, T. 33 N., R. 8 E., Grundy County; they are separated from each other by thin beds of coal. The lowermost underclay varies from 10 to 12 feet thick and extends downward to pre-Pennsylvanian beds. This material is dark gray, slightly carbonaceous, unbedded, and slightly sandy with the sandiness increasing downward. Relatively few slickensided fracture surfaces are present, and the clay possesses an angular fracture or occasionally a conchoidal fracture. The clay in the uppermost few feet of this bed is more carbonaceous and has more slickensided fracture surfaces than that in the lower part. Occasionally some of the uppermost clay is hard, brittle, and dense like flint clay.

The middle underclay is from 3 to 5 feet thick and is frequently separated into several beds by thin coal streaks. The material is dark gray brown, very carbonaceous, unbedded, possesses many slickensided fracture surfaces, and exhibits no definite vertical variation in characteristics.

At some places in the clay pit, the coal overlying the middle underclay is immediately overlain by Pleistocene or Recent sediments; at other places another underclay with a maximum thickness of 6 feet intervenes. Occasionally this uppermost underclay is overlain immediately by a clayey limestone a few inches thick. The clay is green to gray; it is carbonaceous, nonbedded, and possesses many slickensided fracture surfaces.

*Mineral Composition.*—Fraction A of the lower underclay (Samples 1a-1d) is a mixture of approximately equal amounts of kaolinite and

illite (Grim, Bray, and Bradley, 1937) with very small amounts of other constituents,[2] chiefly quartz and organic material. Since $K_2O$ is a component of illite and not of the other constituents, the increase in quantity of $K_2O$ downward (Table 1) indicates a relative increase in the abundance of illite. The approximately constant $SiO_2$ to $R_2O_3$ ratio suggests no appreciable variation in the quartz content of this fraction. The FeO and MgO shown by the analyses are components of illite.

Fraction B increases from about 30 per cent of the total in the uppermost part of the lower underclay to about 50 per cent in the lower part. The fraction is composed largely of quartz grains whose maximum diameter ranges from 0.06 mm. in the upper part to 0.12 mm. in the lower part. White mica is very common, and feldspar (orthoclase, microcline, albite) is a common constituent, particularly in the lower part of this underclay. Chloritic mica, kaolinite, calcite, pyrite, zircon, tourmaline, and rutile are rare.

The flint-like clay of the lower underclay contains also the constituents noted above. Thin sections show the matrix to possess a dense appearance; this is interpreted as indicating slight silicification.

Fraction A of the middle underclay (Samples 1e-1g) is composed essentially of kaolinite with some illite and a very small amount of quartz and organic material. A comparison of the $K_2O$ content (Table 1) of this underclay and the lower one shows that illite is more abundant in the lower underclay. The downward increase in $K_2O$ indicates an increase from top to bottom of illite with an attendant decrease in kaolinite. The $H_2O+$ values are in accord with this conclusion since the $H_2O+$ values of kaolinite are higher than those of illite. The analytical data indicate no noteworthy vertical variation in the abundance of quartz and organic material.

Fraction B makes up about 35 per cent of the middle underclay. It is composed mainly of quartz in grains up to 0.1 mm. in diameter. Distinct books of kaolinite are common in the uppermost part, and flakes of white mica are common in the lower part of this bed. Grains of feldspar (orthoclase), frequently partially altered, and pyrite are fairly common also in the lower part. Calcite, chloritic mica, zircon, and tourmaline are very rare.

The results of the supercentrifuge fractionation analyses of the middle underclay given in Table 2 show that a slightly larger amount of illite in the lowermost material is the only appreciable vertical variation in the clay mineral constitution of this underclay. The organic content, as in-

[2] Some analytical data derived from supercentrifuge fractions of two underclays suggest the presence of a small amount of the montmorillonite type of clay mineral. A trace of this mineral may be present in all underclays.

TABLE 1.—*Chemical analyses of Fraction A from two lower Pottsville underclays* *

Exposure in a working clay pit in the Goose Lake area, NW. ¼ NE. ¼ sec. 11, T. 33 N., R. 8 E., Grundy County

| | Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $SiO_2/Al_2O_3$ | $SiO_2/R_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0– 6 inches below upper coal..... | 1e | 52.45 | 32.01 | .04 | .71 | .81 | none | none | 1.22 | 1.46 | 11.34 | 100.04 | 3.32 | 11.15 | 2.79 | 2.79 |
| 15–20 " " " " ..... | 1f | 52.03 | 32.91 | .33 | .66 | .90 | none | .31 | 1.77 | 1.59 | 10.32 | 100.82 | 1.68 | 10.14 | 2.68 | 2.66 |
| 24–30 " " " " ..... | 1g | 51.77 | 32.30 | .68 | .58 | .94 | none | .33 | 2.20 | 2.03 | 9.65 | 100.48 | 1.62 | 9.29 | 2.70 | 2.68 |
| 10–15 inches below lower coal..... | 1a | 53.24 | 30.93 | .39 | .80 | .83 | none | .30 | 2.16 | 2.12 | 9.74 | 100.51 | 2.81 | 9.45 | 2.93 | 2.90 |
| 25–30 " " " " ..... | 1b | 53.94 | 29.91 | .78 | .80 | 1.17 | none | .05 | 2.83 | 1.90 | 9.06 | 100.44 | 1.72 | 8.72 | 3.07 | 3.02 |
| 60–65 " " " " ..... | 1c | 52.88 | 29.47 | 1.23 | .83 | 1.22 | none | .46 | 2.90 | 1.83 | 9.31 | 100.13 | 2.80 | 8.73 | 3.05 | 2.97 |
| 90–96 " " " " ..... | 1d | 52.71 | 29.09 | 1.16 | .96 | 1.15 | none | .31 | 3.45 | 2.11 | 9.32 | 100.26 | 2.09 | 8.96 | 3.08 | 3.00 |

* Chemical analyses used throughout this paper were made under the supervision of Dr. O. W. Rees, Associate Chemist, Illinois State Geological Survey.

| Sample No. | Fraction* | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|
| le (0-6 inches below upper coal) | R | | | |
| | C | 48.17 | 33.60 | .89 |
| | F | 44.01 | 35.67 | .95 |
| | S | 45.14 | 29.50 | 1.32 |
| lf (15-20 inches below upper coal) | R | 67.61 | 18.85 | 1.92 |
| | C | 47.79 | 35.29 | 1.03 |
| | F | 46.78 | 34.17 | 2.84 |
| | S | 45.17 | 32.08 | 1.99 |
| lg (24-30 inches below upper coal) | R | | | |
| | C | 48.10 | 33.54 | .98 |
| | F | 47.11 | 33.46 | 1.15 |
| | S | 47.23 | 30.18 | 1.24 |

* R = residue; C = coarse
S = superfine colloid fraction

† S = Strong lines; W = W
Illinois State Geological Surv

TABLE 2.—*Supercentrifuge fractionation, analytical data, and mineral identifications*

| Sample No. | Fraction* | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{R_2O_3}$ | Optical data** | X-ray data† | % of total clay | Mineral identifications†† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| le (0-6 inches below upper coal) | R | | | | | | | | | | | | | | | | | | 67 | Quartz A<br>kaolinite A<br>white mica VC |
| | C | 48.17 | 33.60 | .89 | .55 | .96 | .37 | .32 | 1.82 | 1.74 | 12.33 | 100.75 | 1.75 | 11.32 | 2.44 | 2.39 | Aggregates<br>$\beta$=1.565<br>$\gamma-\alpha$=.015 | kaolinite S<br>illite W<br>quartz W | 22.5 | kaolinite VA<br>illite VC<br>quartz R |
| | F | 44.01 | 35.67 | .95 | 1.16 | 1.12 | .53 | .42 | 1.61 | 1.46 | 13.22 | 100.15 | 3.13 | 12.62 | 2.10 | 2.06 | Aggregates<br>$\beta$=1.575<br>$\gamma-\alpha$=.020 | kaolinite S<br>illite W | 4.8 | kaolinite VA<br>illite VC |
| | S | 45.14 | 29.50 | 1.32 | 1.06 | 1.37 | 1.02 | .54 | 2.38 | .83 | 17.14 | 100.30 | 4.46 | 11.44 | 2.60 | 2.54 | Homogeneous aggregates<br>$\gamma$=1.585; (−)<br>$\gamma-\alpha$=.020; 2V small | kaolinite<br>illite | 5.7 | kaolinite<br>illite |
| lf (15-20 inches below upper coal) | R | 67.61 | 18.85 | 1.92 | .46 | .20 | .20 | .48 | .93 | 1.00 | 8.33 | 99.98 | .67 | 7.09 | | | | | 54 | quartz A<br>kaolinite A<br>white mica VC |
| | C | 47.79 | 35.29 | 1.03 | .59 | .59 | .47 | .48 | 1.41 | 1.37 | 11.44 | 100.46 | 1.12 | 11.14 | 2.30 | 2.26 | Aggregates<br>$\beta$=1.572<br>$\gamma-\alpha$=.012 | kaolinite S<br>illite W<br>quartz W | 33 | kaolinite VA<br>illite VC<br>quartz R |
| | F | 46.78 | 34.17 | 2.84 | .62 | .81 | .51 | .25 | 1.74 | 1.26 | 11.62 | 100.60 | 1.53 | 11.25 | 2.23 | 2.11 | Homogeneous aggregates<br>$\gamma$=1.586; (−)<br>$\gamma-\alpha$=.022; 2V small | kaolinite S<br>illite W | 6 | kaolinite VA<br>illite VC |
| | S | 45.17 | 32.08 | 1.99 | | 1.40 | .33 | | | | 14.99 | 95.96 | 2.98 | | 2.40 | 2.30 | Homogeneous aggregates<br>(−); 2V small<br>$\gamma$=1.585; $\gamma-\alpha$=.020 | kaolinite<br>illite | 7 | kaolinite<br>illite |
| lg (24-30 inches below upper coal) | R | | | | | | | | | | | | | | | | | | 62 | quartz A<br>kaolinite A<br>wbite mica VC |
| | C | 48.10 | 33.54 | .98 | .40 | .97 | .34 | .06 | 2.55 | 2.66 | 10.52 | 100.12 | 1.31 | 10.35 | 2.44 | 2.39 | Aggregates<br>$\beta$=1.565<br>$\gamma-\alpha$=.015 | kaolinite S<br>illite S<br>quartz W | 20.7 | kaolinite VA<br>illite VA<br>quartz R |
| | F | 47.11 | 33.46 | 1.15 | .53 | 1.12 | .24 | .06 | 2.85 | 2.44 | 10.96 | 99.92 | 1.88 | 10.70 | 2.39 | 2.34 | Aggregates<br>$\beta$=1.575<br>$\gamma-\alpha$=.020 | kaolinite S<br>illite S | 8 | kaolinite VA<br>illite VA |
| | S | 47.23 | 30.18 | 1.24 | .69 | 1.28 | .25 | .50 | 3.54 | 1.70 | 13.28 | 99.89 | 2.95 | 13.10 | 2.66 | 2.59 | Homogeneous aggregates;<br>(−); 2V small<br>$\gamma$=1.585; $\gamma-\alpha$=.025 | kaolinite<br>illite | 9.3 | kaolinite<br>illite |

* R = residue; C = coarse colloid fraction; F = fine colloid fraction; S = superfine colloid fraction.

† S = Strong lines; W = Weak lines; X-ray analyses by Dr. W. F. Bradley, Illinois State Geological Survey.

** Optical measurements on all samples were made using the immersion liquids described by Glass (1934).

†† VA = 40%+ VC = 25%−15% R = 10%−5%
A = 40%−25% C = 15%−10% VR = −5%

dicated by the difference between loss on ignition and $H_2O+$ values, is highest in the uppermost sample and tends to be concentrated in the superfine colloid fraction.

The green clay of the upper underclay is composed almost wholly (Grim and Bradley) of a distinctive clay mineral belonging to the illite group. The gray clay contains, in addition to this constituent, kaolinite varying up to 20 per cent. Quartz in unsorted grains with a maximum diameter of 0.06 mm. makes up about 15 per cent of the total material. Flakes of white mica and grains of pyrite are present occasionally.

### UNDERCLAY BELOW COAL NO. 8 ALONG SALT FORK CREEK, VERMILION COUNTY

*Outcrop Characteristics.*—A bed of underclay about 6 feet thick underlying Coal No. 8 is exposed along Salt Fork Creek, W. ½ sec. 31, T. 19 N., R. 13 W., Vermilion County. The clay becomes sandy toward its base and grades rapidly into the underlying sandstone member of the cyclothem. A gradual change from noncalcareous to calcareous clay takes place about 15 inches beneath the coal. Carbonaceous material and slickensided fracture surfaces are most abundant in the uppermost clay. Limonitic staining of the upper part of the clay is common, particularly in a narrow zone about 15 inches beneath the coal.

*Mineral Composition.*—Fraction A (Samples 7a-7d) is composed of illite with minor amounts of quartz and a very small amount of organic material. Calcite is also present in the calcareous samples. Chemical data (Table 8) indicate no vertical variations in the composition of the clay mineral constituent of this fraction.

Fraction B varies from about 10 per cent of the total clay directly beneath the coal to about 50 per cent in the lowermost part. Quartz is the dominant constituent in the uppermost horizons, calcite and quartz in the lower horizons. Pyrite, white mica, chloritic mica, orthoclase, zircon, tourmaline, and glauconite are rare.

In the supercentrifuge analytical data the higher $SiO_2$ to $R_2O_3$ and $SiO_2$ to $Al_2O_3$ ratios, the $H_2O-$ and alkali values, and the optical data (Table 3) together suggest the presence of a small amount of the montmorillonite-type mineral in the superfine fraction of all samples. The higher $SiO_2$ to $R_2O_3$ and $SiO_2$ to $Al_2O_3$ ratios in the superfine fractions of the uppermost samples suggest that montmorillonitic material may be slightly more abundant in the upper part of this horizon. The other analytical data do not concur with this suggestion; they indicate that there is no appreciable vertical variation in the clay mineral constitution. It may be concluded that even a small vertical variation in the content of montmorillonite-type material, which is the only variation for which there is any suggestion, is questionable.

The data show the concentration of the organic material in the superfine fraction and indicate that it is most abundant in the upper part of the horizon. No vertical variations in the textural characteristic of the clay are indicated.

*Base-Exchange Capacity Determinations.*—It has been shown recently (Endell, Hofmann, and Maegdefrau, 1935; Grim and Bray, 1936) that the seat of the inorganic base-exchange capacity possessed by argillaceous materials is in their clay mineral content and that different clay minerals possess widely different exchange capacities. As a consequence, determination of base-exchange capacities for a series of clays that contain about the same quantity of nonclay mineral constituents and the same size grade distribution of all constituents should indicate any appreciable variation in the species of clay minerals present. This fact is well known to many soil investigators (Bray, 1930) who have recognized the variation in exchange capacity in different horizons of a soil profile as largely reflecting differences in mineral composition. Various types of soil tend to have a characteristic base-exchange capacity curve for the profile as a whole. The values given in Table 4 were obtained on samples collected at 3-inch intervals from directly beneath the coal to a point where the underclay becomes distinctly calcareous. In view of the uniform texture and nonclay mineral fraction of the samples, the base-exchange values afford strong evidence that the clay mineral content of this underclay

TABLE 4.—*Base-exchange capacity values**

From underclay beneath coal No. 8, W. ½ sec. 31, T. 19 N., R. 13 W., Vermilion County

| Sample No. | Depth beneath coal | Exchange capacity in milli-equivalents per 100 grams |
|---|---|---|
| | (inches) | |
| 7a 1 | 0– 3 | 17.4 |
| 7a 2 | 3– 6 | 16.5 |
| 7b 1 | 6– 9 | 16.7 |
| 7b 2 | 9–12 | 17.2 |
| 7c 1 | 12–15 | 17.2 |
| 7c 2 | 15–18 | 17.3 |
| 7d 1 | 18–21 | 16.9 |
| 7d 2 | 21–24 | 17.3 |
| 7e 1 | 24–27 | 17.5 |

* Determinations made by R. H. Bray, Assistant Chief in Soil Survey Analysis, College of Agriculture, University of Illinois.

| Sample No. | Fraction* | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ |
|---|---|---|---|---|
| 7a (2-6 inches below coal No. 8) | R | | | |
| | C | 51.63 | 25.27 | 4.[illegible] |
| | F | 51.02 | 26.25 | 5.[illegible] |
| | S | 51.67 | 21.85 | 5.[illegible] |
| 7b (6-12 inches below coal No. 8) | R | 62.52 | 18.48 | 3.[illegible] |
| | C | 51.39 | 26.65 | 3.[illegible] |
| | F | 51.22 | 25.91 | 4.[illegible] |
| | S | 52.18 | 21.97 | 5.[illegible] |
| 7c (12-18 inches below coal No. 8) | R | | | |
| | C | 51.41 | 26.39 | 5.2 |
| | F | 50.46 | 26.42 | 5.3 |
| | S | 48.50 | 23.62 | 5.3 |
| 7d (18-24 inches below coal No. 8) | R | | | |
| | C | 51.83 | 26.23 | 3.8 |
| | F | 51.11 | 26.33 | 4.2 |
| | S | 50.29 | 24.60 | 3.8 |

Since carbonates are rem
fractionation, the presence o

* R = residue; C = coars
S = superfine colloid fractio

† S = Strong lines; W = V
Illinois State Geological Sur

TABLE 3.—*Supercentrifuge fractionation, analytical data, and mineral identifications*

| Sample No. | Fraction* | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $\frac{SiO_2}{Al_2O_3}$ | $\frac{SiO_2}{R_2O_3}$ | Optical data** | X-ray data† | % of total clay | Mineral identifications†† |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7a (2-6 inches below coal No. 8) | R | | | | | | | | | | | | | | | | | | 66 | illite VA<br>quartz A |
| | C | 51.63 | 25.27 | 1.56 | 1.90 | 2.49 | .53 | .29 | 6.06 | 1.21 | 6.37 | 100.31 | 3.15 | 6.42 | 3.47 | 3.11 | Aggregates<br>$\beta=1.580$<br>$\gamma-\alpha=.025$ | illite<br>quartz ? | 18 | illite<br>quartz (?) |
| | F | 51.02 | 26.25 | 5.90 | .83 | 2.82 | .16 | .05 | 6.12 | .81 | 6.68 | 100.64 | 2.50 | 6.55 | 3.29 | 2.88 | Homogeneous aggregates; (−); 2V small<br>$\gamma=1.588$; $\gamma-\alpha=.030$ | illite | 52 | illite |
| | S | 51.67 | 21.85 | 5.08 | .98 | 2.51 | .94 | 1.64 | 5.28 | .39 | 9.87 | 100.21 | 4.41 | 7.82 | 4.00 | 3.48 | Aggregates: mainly<br>$\beta=1.575$; $\gamma-\alpha=.025$<br>some $n=1.535$ | illite | 10.8 | illite<br>montmorillonite-type clay mineral (?) |
| 7b (6-12 inches below coal No. 8) | R | 62.52 | 18.48 | 3.33 | 2.05 | 2.13 | nil | .61 | 4.03 | .84 | 6.10 | 100.09 | .86 | 4.90 | 5.76 | 5.16 | | | 70 | illite VA<br>quartz A |
| | C | 51.39 | 26.65 | 3.72 | 2.06 | 2.53 | .22 | .18 | 6.12 | .96 | 6.91 | 100.74 | 1.52 | 6.82 | 3.28 | 3.01 | Aggregates<br>$\beta=1.580$<br>$\gamma-\alpha=.025$ | illite<br>quartz ? | 17 | illite<br>quartz ? |
| | F | 51.22 | 25.91 | 4.59 | 1.70 | 2.84 | .16 | .17 | 6.09 | .53 | 7.49 | 100.70 | 1.45 | 7.14 | 3.36 | 3.02 | Homogeneous aggregates; (−); $2V=5°\pm$<br>$\gamma=1.588$; $\gamma-\alpha=.033$ | illite | 5.4 | illite |
| | S | 52.18 | 21.97 | 5.70 | | 2.33 | .69 | 1.35 | 5.42 | .42 | 10.62 | 100.68 | 2.19 | 8.00 | 4.03 | 3.45 | Aggregates<br>$\beta=1.565$<br>$\gamma-\alpha=.025$ | illite | 7.6 | illite<br>montmorillonite-type clay mineral (?) |
| 7c (12-18 inches below coal No. 8) | R | | | | | | | | | | | | | | | | | | 70 | illite VA<br>quartz A |
| | C | 51.41 | 26.39 | 5.21 | 1.06 | 2.86 | .23 | .16 | 5.75 | 1.08 | 6.45 | 100.60 | 2.91 | 6.38 | 3.31 | 2.93 | Aggregates<br>$\gamma=1.580$<br>$\gamma-\alpha=.030$ | illite<br>quartz ? | 14 | illite<br>quartz (?) |
| | F | 50.46 | 26.42 | 5.39 | .99 | 2.99 | .67 | .12 | 5.82 | 1.02 | 6.73 | 100.61 | 3.37 | 7.05 | 3.25 | 2.87 | Homogeneous aggregates; (−); $2V=5°\pm$<br>$\gamma=1.588$; $\gamma-\alpha=.033$ | illite | 5.5 | illite |
| | S | 48.50 | 23.62 | 5.32 | .82 | 2.62 | 1.29 | .77 | 5.35 | .47 | 11.80 | 100.56 | 3.35 | 8.78 | 3.49 | 3.06 | Same as 7cF | illite | 10.5 | illite<br>montmorillonite-type clay mineral (?) |
| 7d (18-24 inches below coal No. 8) | R | | | | | | | | | | | | | | | | | | 68 | illite VA<br>quartz A |
| | C | 51.83 | 26.23 | 3.84 | 1.84 | 2.51 | .27 | .32 | 6.00 | 1.22 | 6.33 | 100.41 | 2.39 | 6.40 | 3.36 | 3.07 | Aggregates<br>$\beta=1.580$<br>$\gamma-\alpha=.025$ | illite<br>quartz ? | 15.5 | illite<br>quartz (?) |
| | F | 51.11 | 26.33 | 4.23 | 1.79 | 2.55 | .43 | .27 | 6.08 | 1.00 | 6.77 | 100.56 | 2.20 | 6.70 | 3.30 | 3.00 | Homogeneous aggregates; (−); $2V=5°\pm$<br>$\gamma=1.590$; $\gamma-\alpha=.030$ | illite | 6.7 | illite |
| | S | 50.29 | 24.60 | 3.89 | 1.81 | 2.38 | .46 | 1.10 | 5.65 | .19 | 10.19 | 100.56 | 2.27 | 9.76 | 3.47 | 3.16 | Same as 7dF | illite | 9.8 | illite<br>montmorillonite-type clay mineral (?) |

Since carbonates are removed in preparing material for supercentrifuge fractionation, the presence of calcite is not indicated.

* R = residue; C = coarse colloid fraction; F = fine colloid fraction; S = superfine colloid fraction.

† S = Strong lines; W = Weak lines; X-ray analyses by Dr. W. F. Bradley, Illinois State Geological Survey.

** Optical measurements on all samples were made using the immersion liquids described by Glass (1934).

†† VA = 40%+ VC = 25%−15% R = 10%−5%
A = 40%−25% C = 15%−10% VR = −5%

is uniform at the present time from the coal downward into the calcareous zone. The values possess no similarity to those obtained in a vertical sequence of samples from recent soils in which there is profile development. This underclay was chosen for base-exchange capacity determinations because it is one whose characteristics in the section exposed possess a suggestive resemblance to those of many soil profiles.

### ADDITIONAL UNDERCLAYS (SUMMARY TABLES)

Analytical data, including mineral identifications and chemical analyses of additional samples of underclay taken in sequence at varying depths beneath coals, are summarized in Tables 5 to 8. Similar analytical data for miscellaneous underclay samples, not collected at definite depths beneath coals, are summarized in Tables 9 and 10.

## TEXTURAL CHARACTERISTICS

The outstanding textural characteristic of most underclays is the absence of uniformity of orientation of the minute flake-shaped clay mineral particles which make up the bulk of the clay. The individual particles, occurring in random orientation,[3] are usually less than 0.003 mm. in diameter. Occasionally irregular, indistinctly bounded masses show slight aggregate orientation (Plate 1, a), and commonly there is a thin zone parallel to the slickensided fracture surfaces or surrounding grains of quartz (Plate 1, b) in which there is a fair degree of uniformity of orientation.

Underclays with a layered structure differ texturally from those without lamination or bedding by having a relatively uniform aggregate orientation of the clay mineral particles.

Occasionally underclays exhibit a pellet texture (Plate 1, c and d)—*i.e.*, small round aggregates of clay minerals and fine quartz are scattered through a matrix of the same material. The pellet masses are usually sharply bounded from the matrix by a shell of organic material. At times they are distinctive because of slightly different particle size, degree of uniformity of orientation of the clay mineral flakes, or abundance of organic material. The pellets are frequently 0.1 to 0.25 mm. in diameter, although some several millimeters in diameter have been found. No general tendency toward any orientation of the pellets has been noted.

Organic material occurs as an irregularly disseminated pigment and in black opaque spots and streaks. The quartz grains, feldspars, white mica books, and other constituents of Fraction B are usually irregularly scattered through the clay mineral particles. Occasionally the larger quartz grains and flakes of white mica are concentrated in small lenticular zones.

[3] This is in contrast to the Pennsylvanian shales in which the large dimensions of all flakes are approximately parallel. *See* Grim (1935).

TABLE 5.—*Summary of mineral analyses*

Samples taken in sequence at varying depths beneath coals

| Stratigraphic position | Location | Mineral composition | | Remarks |
|---|---|---|---|---|
| | | Fraction A | Fraction B | |
| Underclay coal No. 2<br>Samples 2a–2e | NW. 1/4 SW. 1/4, sec. 5, T. 33 N., R. 4 E., La Salle County.<br>Working clay pit. | Kaolinite with small amounts of illite, quartz, and organic material. | About 50% of total sample in upper part of horizon; 35% in lower part. Dominantly quartz; white mica and pyrite common; chloritic mica, orthoclase, zircon, tourmaline, and calcite very rare. | Relative abundance of quartz and carbonaceous material decrease downward. No appreciable vertical variation in clay mineral constitution indicated. |
| Underclay coal No. 2<br>Samples 3a–3d. | NE. 1/4, sec. 4, T. 7 S., R. 4 W., Jackson County.<br>Creek bank near Campbell Hill. | Illite and kaolinite in about equal proportions. Kaolinite increases slightly in relative abundance downward. Quartz and organic material very minor constituents. | 20% to 40% of total sample. Dominantly quartz; white mica, pyrite, gypsum, orthoclase, albite, zircon, tourmaline, rutile, garnet, epidote common to very rare. | Directly beneath coal, clay has much carbonaceous material and is highly fractured; carbonaceous material and fracturing decrease downward. Pronounced zone of limonitic staining occurs 6–14 inches below the coal. |
| Underclay coal No. 6<br>Samples 4a–4d | S. 1/2, sec. 9, T. 11 N., R. 9 E., Marshall County. Creek bank near Chillicothe. | Illite with minor amounts of quartz, calcite, and organic material. Calcite very scant in uppermost samples. | About 20% of total sample. Uppermost samples dominantly quartz with white mica, pyrite, chloritic mica, calcite, orthoclase, microcline, albite, gypsum, barite, rutile, tourmaline, garnet, epidote, pyroxene, and glauconite (?) as common to very rare constituents; lowermost samples contain abundant calcite also. | About 12 inches below coal, rapid transition from noncalcareous to calcareous underclay. Abundance of carbonaceous material and fracturing decrease downward. In a zone 12 to 54 inches below coal limonitic staining is pronounced. Slight downward increase in abundance of quartz. |
| Underclay coal No. 6<br>Samples 5a–5d | NE. 1/4 SE. 1/4, sec. 25, T. 9 S., R. 4 E., Williamson County.<br>Railroad cut near Carrier Mills. | Illite with minor amounts of quartz, calcite, and organic material. Calcite very scant in uppermost samples. | About 35% of total sample. Uppermost samples dominantly quartz with very minor amounts of white mica, pyrite, orthoclase, albite, microcline, zircon, garnet, rutile, tourmaline, epidote, amphibole, barite, gypsum; lowermost samples contain abundant calcite also. | About 20 inches below coal the clay changes rapidly from noncalcareous to calcareous. Abundance of carbonaceous material and fracturing decrease rapidly downward. A zone 12 to 20 inches below coal contains appreciable limonitic staining. Pyrite is particularly abundant in uppermost clay. |
| Underclay coal No. 8<br>Samples 6a–6e | NE. 1/4 NW. 1/4, sec. 2, T. 9 N., R. 7 W., Macoupin County.<br>Creek bank near Carlinville. | Illite with minor amounts of quartz and organic material. Calcite also present in all but uppermost clay. | About 25% of total sample. Uppermost samples dominantly quartz with pyrite, orthoclase, white mica, chloritic mica, zircon, tourmaline, garnet, rutile, apatite, biotite, barite as rare constituents; lowermost samples contain also abundant calcite. | About 8 inches below coal, clay rapidly changes from noncalcareous to calcareous. Uppermost clay contains carbonaceous material, is well fractured, and stained by limonite; these characteristics rapidly disappear downward. |

TABLE 6.—*Chemical analyses*

Of fraction A obtained from underclays of coal No. 2

| Location: NW. 1/4 SW. 1/4 sec. 5, T. 33 N., R. 4 E., La Salle County | Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $CO_2$ | $SiO_2/Al_2O_3$ | $SiO_2/R_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0– 6 inches below coal..... | 2a | 55.21 | 30.48 | .18 | .75 | .68 | none | .10 | .72 | 1.81 | 10.71 | 100.64 | 2.08 | 10.07 | ..... | 3.07 | 3.07 |
| 8–12 " " " ..... | 2b | 51.21 | 33.00 | .64 | .71 | .71 | none | .08 | .57 | 2.05 | 11.68 | 100.65 | 3.01 | 11.15 | ..... | 2.63 | 2.61 |
| 24–30 " " " ..... | 2c | 51.32 | 33.59 | .78 | .52 | .63 | none | .10 | .55 | 1.34 | 11.72 | 100.55 | 2.05 | 11.35 | ..... | 2.60 | 2.57 |
| 40–45 " " " ..... | 2d | 48.30 | 34.49 | 1.06 | .61 | .67 | none | .31 | .55 | 2.02 | 12.50 | 100.51 | 2.85 | 12.33 | ..... | 2.38 | 2.34 |
| 55–60 " " " ..... | 2e | 49.02 | 34.94 | 1.11 | .34 | .62 | none | .07 | .70 | 1.59 | 12.22 | 100.61 | 1.36 | 11.88 | ..... | 2.39 | 2.35 |
| Location: NE. 1/4 sec. 4, T. 7 S., R. 4 W., Jackson County | | | | | | | | | | | | | | | | | |
| 0– 6 inches below coal..... | 3a | 54.44 | 23.93 | 3.39 | .46 | 1.95 | 2.02 | .33 | 3.21 | 1.38 | 7.94 | 100.05 | 4.50 | 7.69 | n.d. | 3.86 | 3.54 |
| 8–14 " " " ..... | 3b | 59.11 | 24.79 | 2.73 | .69 | 1.23 | .58 | .05 | 2.62 | 1.00 | 7.94 | 100.74 | 3.55 | 7.86 | n.d. | 4.05 | 3.79 |
| 22–28 " " " ..... | 3c | 58.35 | 25.52 | 2.31 | .97 | 1.23 | .47 | .06 | 2.37 | .99 | 8.09 | 100.36 | 2.35 | 8.05 | .04 | 3.89 | 3.68 |
| 44–48 " " " ..... | 3d | 57.81 | 25.50 | 2.06 | 1.13 | 1.11 | .45 | .13 | 2.22 | 1.09 | 8.31 | 99.81 | 2.15 | 8.01 | .05 | 3.85 | 3.66 |

TABLE 7.—*Chemical analyses*

Of fraction A from underclays of coal No. 6

| Location: S. 1/2 sec. 9, T. 11 N., R. 9 E., Marshall County | Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $CO_2$ | $SiO_2/Al_2O_3$ | $SiO_2/R_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 inches below coal..... | 4a | 56.40 | 22.84 | 2.02 | 1.63 | 1.72 | .94 | .26 | 4.42 | 1.18 | 8.53 | 99.94 | 3.20 | 7.06 | n.d. | 4.19 | 3.96 |
| 12 " " " ..... | 4b | 58.16 | 22.85 | 1.92 | 1.53 | 1.95 | 1.20 | .31 | 4.86 | 1.06 | 6.33 | 100.17 | 5.67 | 5.40 | .05 | 4.33 | 4.10 |
| 18 " " " ..... | 4c | 49.67 | 18.59 | 1.74 | 2.69 | 2.85 | 7.04 | .34 | 3.80 | .90 | 12.37 | 99.99 | 2.97 | 4.31 | 6.62 | 4.55 | 4.28 |
| 30 " " " ..... | 4d | 41.73 | 15.10 | 1.11 | 2.30 | 2.21 | 15.23 | .30 | 3.21 | .88 | 17.81 | 99.88 | 2.21 | 4.58 | 12.52 | 4.69 | 4.48 |
| Location: SE. 1/4 sec. 25, T. 9 S., R. 4E., Williamson County | | | | | | | | | | | | | | | | | |
| 0– 6 inches below coal.... | 5a | 56.68 | 23.19 | 1.91 | 1.71 | 1.90 | 1.48 | .45 | 4.47 | 1.37 | 6.83 | 99.99 | 2.09 | 6.54 | .08 | 4.16 | 3.95 |
| 6–12 " " " .... | 5b | 58.30 | 21.91 | 1.94 | 1.75 | 2.02 | 1.93 | .49 | 4.15 | 1.49 | 6.53 | 100.51 | 2.93 | 5.86 | .06 | 4.53 | 4.29 |
| 12–20 " " " .... | 5c | 55.78 | 22.83 | 2.35 | 1.68 | 2.39 | 2.15 | .42 | 4.71 | 1.46 | 6.49 | 100.46 | 1.43 | 5.98 | .09 | 4.15 | 3.91 |
| 30 " " " .... | 5d | 51.66 | 21.56 | 2.52 | 1.95 | 2.39 | 5.55 | .67 | 4.12 | 1.25 | 8.45 | 100.12 | 2.36 | 5.33 | 2.88 | 4.88 | 3.79 |

TABLE 8.—*Chemical analyses*

Of fraction A obtained from underclays of coal No. 8

| Location: NE. 1/4 NW. 1/4 sec. 2, T. 9 N., R. 7 W., Macoupin County | Sample No. | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | Ignition loss | Total | $H_2O-$ | $H_2O+$ | $CO_2$ | $SiO_2/Al_2O_3$ | $SiO_2/R_2O_3$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1– 4 inches below coal..... | 6a | 57.01 | 22.23 | 2.74 | 2.33 | 3.90 | 1.13 | .07 | 2.66 | 1.15 | 7.00 | 100.22 | 5.11 | 6.92 | | 4.36 | 4.04 |
| 5– 8 " " " ..... | 6b | 58.36 | 21.45 | 2.99 | 1.92 | 3.79 | 1.08 | .29 | 2.34 | 1.09 | 6.71 | 100.02 | 4.24 | 6.55 | .08 | 4.63 | 4.29 |
| 10–12 " " " ..... | 6c | 59.51 | 21.55 | 2.14 | 2.10 | 3.45 | 1.29 | .18 | 2.65 | 1.10 | 6.43 | 100.40 | 4.81 | 6.18 | 2.23 | 4.70 | 4.43 |
| 12–18 " " " ..... | 6d | 51.72 | 18.74 | 2.25 | 2.11 | 3.26 | 7.20 | .32 | 2.52 | 1.05 | 10.60 | 99.77 | 3.40 | 5.67 | 5.07 | 4.68 | 4.35 |
| 24–34 " " " ..... | 6e | 49.39 | 20.32 | 1.90 | 2.31 | 3.26 | 7.92 | .37 | 2.53 | 1.00 | 11.19 | 100.19 | 3.63 | 5.81 | 6.43 | 4.14 | 3.90 |
| Location: W. 1/2 sec. 31, T. 19 N., R. 13 W., Vermilion County | | | | | | | | | | | | | | | | | |
| 2– 6 inches below coal..... | 7a | 52.90 | 26.06 | 2.02 | 2.92 | 1.66 | 1.14 | .45 | 5.23 | .76 | 7.35 | 100.49 | 2.57 | 6.22 | .02 | 3.46 | 3.29 |
| 6–12 " " " ..... | 7b | 51.94 | 26.41 | 2.09 | 2.90 | 2.20 | 1.21 | .42 | 4.86 | .76 | 7.20 | 99.99 | 3.19 | 6.67 | .11 | 3.34 | 3.18 |
| 12–18 " " " ..... | 7c | 52.90 | 26.61 | 1.51 | 2.61 | 1.92 | 1.43 | .33 | 4.87 | .72 | 7.34 | 100.24 | 2.62 | 6.69 | .44 | 3.38 | 3.26 |
| 18–24 " " " ..... | 7d | 53.30 | 26.76 | 1.30 | 2.62 | 2.18 | 1.38 | .43 | 4.12 | .70 | 7.45 | 100.24 | 3.45 | 6.64 | .08 | 3.39 | 3.29 |
| 36 " " " ..... | 7e | 52.83 | 25.91 | 1.55 | 2.82 | 2.05 | 1.46 | .64 | 4.90 | .72 | 7.43 | 100.31 | 2.99 | 6.54 | .49 | 3.46 | 3.34 |

TABLE 10.—*Chemical analyses*

Of fraction A of miscellaneous underclay samples

| Sample No. | 9a | 9b | 9c | 9d | 11c | 13a | 14 |
|---|---|---|---|---|---|---|---|
| $SiO_2$ | 50.10 | 53.32 | 48.33 | 59.85 | 53.31 | 56.00 | 51.45 |
| $Al_2O_3$ | 33.76 | 31.09 | 33.27 | 25.04 | 29.79 | 27.72 | 26.82 |
| $Fe_2O_3$ | 1.24 | 1.57 | .62 | 2.01 | 1.59 | 2.00 | 2.07 |
| FeO | .46 | .00 | .53 | ..... | ..... | ..... | 3.01 |
| MgO | .52 | .69 | .22 | .51 | .89 | .35 | 1.89 |
| CaO | .49 | .83 | .61 | .49 | .54 | .57 | .65 |
| $Na_2O$ | .32 | .26 | .53 | .24 | .14 | .11 | .29 |
| $K_2O$ | .45 | .59 | 1.27 | 2.84 | 3.19 | 2.13 | 5.15 |
| $TiO_2$ | 1.57 | 1.56 | 2.19 | 1.62 | 1.60 | 2.13 | 1.80 |
| Loss on ignition | 11.05 | 10.36 | 11.95 | 7.90 | 9.15 | 9.75 | 7.23 |
| Total | 99.96 | 100.27 | 99.52 | 100.50 | 100.20 | 100.76 | 100.36 |
| $H_2O+$ | 11.13 | 10.19 | ..... | 7.82 | 9.07 | 9.46 | 7.31 |
| $H_2O-$ | 3.34 | 4.30 | .85 | 1.30 | 1.58 | 2.66 | .87 |

In the kaolinite-rich clays, books of kaolinite attaining a diameter of 0.2 mm. may be scattered through the matrix.

In the calcareous underclays, the calcite occurs in individual grains about 0.1 mm. to —0.001 mm. in diameter. These grains are scattered through the matrix or occur in aggregates several millimeters in diameter. Many of the aggregates, in the uppermost part of the calcareous interval of underclays which grade from noncalcareous to calcareous, have indistinct boundaries and appear "eaten into" (Plate 1, e). At greater depths in the calcareous interval the aggregates are larger, more distinctly separated from the matrix, and commonly possess a distinct nucleus of calcite or matrix material (Plate 1, f).

Texturally all underclays studied are very similar. They differ from each other primarily in the relative abundance of their constituent minerals.

## DISCUSSION OF ANALYTICAL RESULTS

The analytical data show that the underclays of coal No. 2 and older coals are usually completely noncalcareous and are composed essentially of kaolinite with varying small amounts of illite. Underclays of coals younger than coal No. 2 are calcareous or grade downward from noncalcareous to calcareous. Illite is the essential constituent of these clays. The underclay beneath coal No. 7 at places is entirely noncalcareous and contains kaolinite. It is, therefore, an exception to the above generalization. There is a suggestion that a trace of the montmorillonite-type clay

TABLE 9.—*Summary of mineral analyses* and lithologic characteristics of miscellaneous samples of underclay*

| Sample No. | Location | Stratigraphic interval represented by sample | Lithologic character | Mineral composition |
|---|---|---|---|---|
| 15 | Underground mine workings, sec. 26, T. 19 N., R. 5 N., Menard County. | Underclay coal No. 5. | Gray, massive, nongritty clay grading from noncalcareous to calcareous about 7 inches below coal. Slickensided fracture surfaces and carbonaceous material are most abundant in upper 7 inches of clay. About 7 inches below coal there is appreciable limonitic staining. | Composed of illite and quartz with calcite in calcareous material. Quartz in grains to 0.06 mm. in diameter composes about 35% of total clay. Small amounts of limonite and organic material also present. |
| 16 | SW. 1/4 NW. 1/4 sec. 11, T. 7 E., R. 8 N., Peoria County. | Underclay coal No. 7. | Massive, nongritty clay grading from noncalcareous to calcareous about 36 inches below coal. Abundance of carbonaceous material and slickensided fracture surfaces decreases downward. Upper part of clay is gray; lower part green gray. Abundant limonitic staining 25 inches to 36 inches below coal. | Composed of illite, quartz, and very small amount of organic material and limonite. Calcite also present in lowermost clay. Maximum diameter of quartz grains 0.03 mm. |
| 17 | NE. 1/4 SE. 1/4 sec. 31, T. 33 N., R. 2 E., La Salle County. | Underclay coal No. 7. | Massive, slightly gritty, noncalcareous clay Carbonaceous material and slickensided fracture surfaces most abundant directly beneath coal.<br>At this locality 4 feet of underclay exposed. At least 10 feet of noncalcareous underclay known below coal No. 7 in the region of this exposure. | Composed of kaolinite, quartz and illite. Quartz varies in abundance from about 20% in clay directly beneath coal to about 40% in samples 4 feet below coal; maximum diameter varies similarly from 0.12 mm. to 0.25 mm. Illite occurs in flakes larger than 0.002 mm. in diameter. |

* The "heavy" mineral and feldspar content of these underclays is the same as that of the previous underclays. To avoid repetition no mention is made of these constituents.

TABLE 9.—*Summary of mineral analyses* and lithologic characteristics of miscellaneous samples of underclay*

| Sample No. | Location | Stratigraphic interval represented by sample | Lithologic character | Mineral composition |
|---|---|---|---|---|
| 8a | SE. 1/4 NE. 1/4, sec. 35, T. 6 N., R. 10 W., Madison County. | Cheltenham underclay; interval 3 to 7 feet below Seahorne limestone. | Light gray, noncalcareous, massive, slightly carbonaceous, with many slickensided fracture surfaces. | About 65% kaolinite, 25% quartz, a small amount of illite and organic material. Maximum diameter of quartz 0.08 mm., of kaolinite 0.005 mm., of illite 0.01 mm. |
| 8b | SE. 1/4 sec. 35, T. 6 N., R. 10 W., Madison County. | 1- to 8-inch interval in Cheltenham underclay about 6 feet below Seahorne limestone. | Light green, noncalcareous, thinly laminated. Streaks and lenses of quartz and pyrite are interlaminated with the clay. | Clay portion of this sample composed of a distinctive illite (*see* p. 1493) mainly in particles −0.1 micron in diameter. |
| 9a | NW. 1/4 sec. 15, T. 5 N., R. 9 W., Madison County. | Cheltenham underclay horizon below Seahorne limestone. | Dark gray-black, noncalcareous, massive, very carbonaceous, with many slickensided fracture surfaces. | About 85% kaolinite; remainder illite, quartz and organic material. Average diameter of kaolinite 0.001 mm.; maximum diameter of quartz, 0.02 mm. |
| 9b | NE. 1/4 sec. 21, T. 13 N., R. 12 W., Scott County. | Cheltenham underclay horizon below Seahorne limestone. | Gray, noncalcareous, massive, gritty to sandy, slightly carbonaceous with many slickensided fracture surfaces. | Mainly kaolinite and quartz; the latter mineral varying in abundance with grittiness. Small amounts of illite, organic material, and occasional grains of pyrite also present. Average diameter of kaolinite 0.001 mm.; maximum size of quartz 0.1 mm. |
| 9c | SE. 1/4 sec. 7, T. 5 N., R. 3 W., McDonough County. | Lower Pottsville. | Same as 9b. | About 50% kaolinite, 30% quartz, 20% illite, with a small amount of organic material. Maximum diameter of quartz 0.25 mm., of illite 0.1 mm., of kaolinite 0.005 mm. |
| 9d | SE. 1/4 SW. 1/4 SW. 1/4 sec. 8, T. 1 N., R. 1 E., Schuyler County. | Lower Pottsville. | Same as 9b. | Same as 9c, except that kaolinite and illite about equally abundant. |
| 10 | SW. 1/4 NW. 1/4 sec. 10, T. 4 S., R. 5 W., Pike County. | Lower Pottsville; interval 0 to 3 feet below coal. | Light gray, noncalcareous, massive, nongritty, slightly carbonaceous, with many small slickensided fracture surfaces. | Kaolinite with small amounts of illite and quartz. Maximum diameter of quartz 0.06 mm.; average diameter of kaolinite and illite 0.001 mm. |
| 11a | NW. 1/4 NW. 1/4 sec. 30, T. 12 N., R. 11 W., Greene County. | Underclay coal No. 2, 25 feet exposed. | Clay varies laterally and vertically. It is light to dark gray, gritty to nongritty, variably carbonaceous, usually massive with slickensided fracture surfaces. Some of it is crudely laminated and stained with limonite. Occasional nodules of calcite and pyrite are present. | Quartz varies in abundance from 25% to 50%. Remainder is mixture of kaolinite and illite with former mineral more abundant except in laminated material. Trace of organic material and limonite also present; maximum diameter of quartz 0.12 mm.; of illite 0.03 mm.; of kaolinite 0.005 mm. |
| 11b | SW. 1/4 SW. 1/4 sec. 29, T. 12 N., R. 12 W., Greene County. | Lower Pottsville underclay, 8 feet exposed. | Light gray, noncalcareous, massive, becoming very sandy toward base, with few slickensided fracture surfaces. Occasionally stained with limonite. | Quartz variable, averaging about 50%. Remainder kaolinite with appreciable illite. Some quartz grains show mutually accommodating boundaries. Maximum diameter of quartz 0.12 mm.; of kaolinite 0.004 mm.; of illite 0.02 mm. |
| 11c | NE. 1/4 NE. 1/4 sec. 2, T. 10 N., R. 12 W., Greene County. | Underclay coal No. 2, 20 feet exposed. | Light gray, gritty, noncalcareous, massive, slightly carbonaceous with occasional slickensided fracture surfaces and occasional patches showing limonitic staining. | Same as 11b, except quartz less abundant. |
| 13a<br>13b<br>13c | N. 1/2 SW. 1/4 sec. 9, T. 33 N., R. 2 E., La Salle County. | Underclay between coal No. 2 and pre-Pennsylvanian limestone, 10 to 15 feet exposed. | Underclays lithologically divisible as follows from top to bottom: Gray, pyritic, massive, noncalcareous with many slickensided fracture surfaces (13a) 2 to 6 feet thick. Same as above, but green and faintly carbonaceous, 0–18 inches thick (13b). Gray, massive, slightly carbonaceous with many slickensided fracture surfaces, occasionally with calcite nodules, 4–8 feet thick (13c). | Upper horizon; quartz 25% in grains to 0.12 mm., remainder equal parts kaolinite and illite plus some pyrite and organic material. Middle horizon: quartz 25%, remainder a distinctive mineral of the illite group (*see* page 1493) and kaolinite, plus some pyrite. Lower horizon: quartz 25%, remainder kaolinite with small amount of illite and trace of organic material. Proportions of illite and kaolinite vary laterally, but illite always less abundant than in upper horizon. |
| 14 | NE. 1/4 sec. 32, T. 8 S., R. 2 W., Jackson County. | Underclay below an unnumbered coal, 4 feet of underclay exposed. | Gray, carbonaceous, massive, gritty, with some slickensided fracture surfaces. Carbonaceous material and fracture surfaces decrease from base of coal downward. From 6 to 36 inches below coal there is limonitic staining; 22 inches below coal limonite nodules are common. From 40 to 48 inches material rapidly grades to shale. | Underclay throughout and shale into which it grades composed of 50% quartz in grains to 0.15 mm. and 50% illite in flakes averaging 0.003 mm. in diameter. Small amount of kaolinite, organic material, and limonite also present. Underclay and shale differ only in texture. |
| 15 | Underground mine workings, sec. 26, T. 19 N., R. 5 N., Menard County. | Underclay coal No. 5. | Gray, massive, nongritty clay grading from noncalcareous to calcareous about 7 inches below coal. Slickensided fracture surfaces and carbonaceous material are most abundant in upper 7 inches of clay. About 7 inches below coal there is appreciable limonitic staining. | Composed of illite and quartz with calcite in calcareous material. Quartz in grains to 0.06 mm. in diameter composes about 35% of total clay. Small amounts of limonite and organic material also present. |
| 16 | SW. 1/4 NW. 1/4 sec. 11, T. 7 E., R. 8 N., Peoria County. | Underclay coal No. 7. | Massive, nongritty clay grading from noncalcareous to calcareous about 36 inches below coal. Abundance of carbonaceous material and slickensided fracture surfaces decreases downward. Upper part of clay is gray; lower part green gray. Abundant limonitic staining 25 inches to 36 inches below coal. | Composed of illite, quartz, and very small amount of organic material and limonite. Calcite also present in lowermost clay. Maximum diameter of quartz grains 0.03 mm. |
| 17 | NE. 1/4 SE. 1/4 sec. 31, T. 33 N., R. 2 E., La Salle County. | Underclay coal No. 7. | Massive, slightly gritty, noncalcareous clay. Carbonaceous material and slickensided fracture surfaces most abundant directly beneath coal.<br>At this locality 4 feet of underclay exposed. At least 10 feet of noncalcareous underclay known below coal No. 7 in the region of this exposure. | Composed of kaolinite, quartz and illite. Quartz varies in abundance from about 20% in clay directly beneath coal to about 40% in samples 4 feet below coal; maximum diameter varies similarly from 0.12 mm. to 0.25 mm. Illite occurs in flakes larger than 0.002 mm. in diameter. |

* The "heavy" mineral and feldspar content of these underclays is the same as that of the previous underclays. To avoid repetition no mention is made of these constituents.

mineral is present in the finest grade size of most underclays. A distinctive mineral of the illite group occurs as the main constituent of thin beds (8b and 13b) in some kaolinitic underclay horizons. The presence of such thin beds of relatively pure material sharply bounded above and below by underclay composed of kaolinite is of significance in considering the origin of the underclays.

Dickite (Everhart, 1936) has been recorded from some Pennsylvanian underclays elsewhere than in Illinois. At the present time the mineral has not been identified in material from Illinois.

A few underclays show a slight increase downward in the relative abundance of illite (Samples 1a-1d); others (Samples 3a-3e) show a decrease downward. There is a suggestion of a concentration of the montmorillonite-type mineral at or near the top of some underclays, but the evidence for it is not strong. It must be concluded, therefore, that there is no appreciable definite vertical variation in the clay mineral composition of the underclays.

There is no indication of any vertical variation due to long-continued selective weathering. Thus feldspars and ferromagnesian minerals constitute only a small percentage of the total bulk of the underclays, but their presence makes possible a comparison between the degree of weathering which has taken place since the underclays were deposited and the degree of weathering recorded in the weathered zones of glacial deposits (Leighton and MacClintock, 1930). The plastic clay comprising the upper part of the weathered zones of the older drift sheets is known as gumbotil and it contains the montmorillonite-type (Allen, 1930) mineral which in part was formed *in situ* by the alteration of feldspars and ferromagnesian minerals. The less resistant silicates, such as the basic plagioclases which are present in the lower horizons, are absent in gumbotil. The more stable feldspars, albite and microcline, have persisted in gumbotil, indicating selective decomposition. Some of the feldspars in gumbotil are so intricately altered to montmorillonitic material that it is impossible to recognize the boundary between the feldspar and the surrounding clay (Plate 2, a). The alteration starts at the edges of grains and penetrates inward, leaving the boundary between the original mineral and the resulting clay extremely irregular. Ferromagnesian minerals are similarly affected (Plate 2, b) and, as more clay mineral forms, the amount of perishable minerals decreases proportionally. This alteration could not have taken place before deposition, because the soft products of decomposition would have been removed during transportation. After complete alteration no feldspar remains, and its place is occupied entirely by clay minerals. The absence of orthoclase and calcic plagioclase in gumbotil and their presence at lower horizons in the same profile support the

conclusion that these more easily decomposed feldspars have been more completely altered to clay minerals in the gumbotil. Microcline and albite persist in gumbotil because they withstood the alteration that affected orthoclase and calcic plagioclase.

The feldspars of Illinois underclays are either clear and fresh or uniformly spotted throughout with alteration products. The boundaries between the clay minerals and the feldspars are sharp (Plate 2, c), and no appreciable clay minerals have formed at their edges since deposition. All varieties of feldspars, even the less resistant ones, remain at all depths including half an inch to an inch below the coal. There has been no selective removal as in the gumbotil. Any profile development on the underclays did not reach the stage at which silicate decomposition altered the feldspars near the coal more than those at greater depth. The ferromagnesian minerals tells a similar story. In the upper zones of glacial profiles the amount of ferromagnesian minerals is less than that in the lower zones of the same profile, and hornblende and epidote in gumbotil are altered at the edges and along cleavage surfaces. In Illinois underclays the few grains of hornblende and epidote present have sharp unaltered edges, and those close beneath coal are just as fresh as those at greater depth. Chloritic mica, probably in part originally biotite, occurs in the underclays at all depths and is no more altered near the coal than at greater depth. The only pronounced variations in the underclays are in the amounts of calcite, pyrite, limonite, organic material, and quartz.

It may be argued that vertical variations existed prior to the burial of the underclay, and that post-burial mineralogical changes conceal all earlier variations. The careful search made during this study shows that there is no appreciable variation in the chemical composition of the clay mineral fraction of the underclays investigated. Since the clay minerals under consideration (excepting nacrite, dickite, and anauxite, which do not enter the problem) possess different chemical compositions, it is not likely that post-burial mineralogical rearrangement could conceal preburial original differences. For example, in modern soils developed on Pleistocene Peorian loess in Illinois, the soil-forming processes have caused vertical variations in the relative abundance of the clay mineral constituents which are mainly montmorillonite and illite. Chemical analyses of the clay mineral fraction clearly show this by variations in the content of MgO and $K_2O$. If at some later date these soils should be buried and mineralogically rearranged, their vertical variations in magnesia and potash should persist.

Different clay minerals possess different base-exchange capacities. Therefore, the uniform values for this property in the underclay investigated indicate no vertical variation in clay mineral constituents. If post-

burial alterations have concealed any pre-burial variations in base-exchange capacity, such changes should be reflected by variations in chemical composition.

Modern soil-forming processes frequently tend to cause movement of material of colloidal size from one horizon of the profile to another. In Peorian loess soils, a concentration of such material takes place in the B horizon. Granting the possibilities of post-burial changes, any movement of material of colloidal size is largely a movement of clay mineral material and therefore should be manifest by vertical variation in the relative abundance of the clay mineral fraction. The analytical data show no evidence of any vertical variation in the relative abundance of the clay mineral portion of the underclays comparable to soil profiles.

The "eaten into" character of the calcite in the transition zone and the character of the nodular masses which have been deposited around nuclei suggest that some calcite has been leached from the upper horizons and partly redeposited in the lower horizons of underclays which grade from noncalcareous to calcareous. Wanless [4] concluded from field data that the underclays which grade from noncalcareous to calcareous were originally completely calcareous. Petrographic data do not prove or disprove the concept that these underclays were entirely calcareous originally. Under present-day weathering of the glacial deposits in Illinois, which are largely composed of illite like the calcareous underclays, the illite is appreciably altered before all the calcite has been leached. However, climatic conditions are conceivable whereby calcite in extremely minute particles could be leached before the silicate minerals were altered notably.

All available petrographic evidence points to the conclusion that post-deposition and pre-burial processes similar to modern soil-forming processes have exerted little influence on the character of the underclay. Vertical variations in the abundance of calcite, limonite, and organic material in some underclays are the only appreciable results which can be ascribed to such processes. Except for an occasional suggestion of increased content of montmorillonite-type clay mineral in the uppermost portion of a few underclays, there is no evidence suggesting that such processes have caused noteworthy variations in mineral composition similar to those produced in a modern soil profile. It can be concluded, therefore, that some of the underclays yield evidence that they have not been subjected to soil-forming processes, whereas others indicate that they were subjected to such processes only to a very limited degree.

Analyses of subsurface samples (No. 15) show that they possess the same characteristics as outcrop samples. These and other data obtained

[4] Personal communication.

from well records indicate that the characteristics of underclays herein discussed are not the result of processes operating at the present outcrops.

When the underclays grade downward into sandstone or limestone, the change takes place by a relative increase in the content of quartz or calcite, respectively. The transition from underclay to shale takes place by a relative increase in the abundance of illite and a change in texture. The random orientation of the clay mineral particles characteristic of most underclays changes to one in which the flakes have about the same orientation with their long axes parallel to the laminae.

The presence of thin zones parallel to the slickensided surfaces of the underclay in which the clay mineral particles are relatively more uniformly oriented than in the remainder indicate that the slight movement along these surfaces was ample to rearrange slightly the clay minerals in a narrow zone.

## PREVIOUS EXPLANATIONS OF ORIGIN OF UNDERCLAYS

From the vast literature on the origin of clay, some hypotheses have been selected for review here, either because the explanation was applied to underclays or because it merited consideration in other connections.

The underclays of Illinois coals were among the first American clay deposits to be described in a geologic report. Worthen (1866) and Wheeler (1896) advanced the explanation that the underclays were the old soils on which Pennsylvanian plants grew and that plant roots removed iron and alkalies from the clay. This concept has been widely held, although several workers (Hopkins, 1901; Stout, 1923) have shown that it is not in agreement with the fact that the middle and lower parts of some underclays are better ceramically than the upper part. If the extraction of iron and alkalies were due wholly to action of plant roots, one would expect the clay surrounding the roots to contain less of these elements than the clay some distance away, and consequently the clay should exhibit distinct vertical variations of these components.

In Germany the belief is widespread that Tertiary Browncoals have caused the decomposition of underlying igneous rocks. Some investigators are so firmly convinced that the ground waters beneath moors or swamps are the cause of kaolinization that wherever coals are now absent, their former presence is postulated (Lang, 1920) as the agent of such decomposition. Weiss (1910) has carried on experiments to demonstrate that the reducing action of moor-water on greenish and yellowish clay of the Bunter formation brought about the relation he observed in East Thuringia. Yellow clays were placed in flasks containing moor-water and carbon dioxide. To avoid the high iron oxide content of some natural moor-waters, artificial moor-waters were prepared by shaking

freshly gathered turf with water a few times. This water contained no so-called humic acid and only fine particles of organic matter to act as reducing agents. After being in contact with the clay the water responded to tests for ferrous iron. Over a period of 9 weeks, the moor-water was repeatedly changed and carbon dioxide was added; after washing, drying, and igniting, the clay residues were lighter in color than the originals. Weiss concluded from these experiments that carbon dioxide and reducing substances altered clay to kaolin and that through their activity the feldspar in the Bunter arkoses has been kaolinized. Stahl (1912) has observed a greenish decomposition product in kaolin formed by moor-water which he claims is not present in kaolins formed by other means. The greenish tint is due to ferrous iron leached out of biotite and hornblende in the presence of reducing substances.

If the careful observations of Weiss and Stahl are applied to Illinois underclays, it is quite evident that the features of the underclays were not caused by bog-waters, for some of the feldspars of these underclays are free from alteration, and the biotite and hornblende have given up little or no ferrous iron to produce a greenish tint. If the activity of bog-waters is indicated by the kaolinization of feldspar and by the decomposition of biotite and hornblende *in situ,* the activity of bog-waters upon Illinois underclays has been nil. The present condition of the underclays, therefore, cannot be ascribed to the leaching effect of bog-waters upon them after their deposition.

Some investigators (Stremme, 1912; Endell, 1910) ascribe the present condition of underclay to the action of the carbon dioxide which, they believe, is liberated during the transformation of vegetable matter into coal. The action of carbon dioxide would be indicated by alteration of the silicate minerals. As noted previously, such alteration has not taken place.

Some students, who consider the noncalcareous portion of underclays which grade from noncalcareous to calcareous as the leached portion of underclays originally entirely calcareous, explain the leaching as due to the activity of sulphuric acid liberated by the oxidation of pyrite and carried by groundwater which moved along coals as channelways. The abundance of gypsum on the outcrops of some underclays proves clearly that sulphuric acid was active at and near exposed surfaces. Leached zones, however, are not limited to outcrops, inasmuch as underclays in some of the deepest coal mines of the State are leached. At a depth of 470 feet below the surface in Orient No. 1 Mine, West Frankfort, secondary calcite has been deposited in the underclay below coal No. 6. It is difficult to understand why calcite was deposited here and gypsum at the surface, if leaching at both places took place as sulphate solutions. A

perplexing problem in this connection is the source of the oxygen required to oxidize pyrite at depth, for Parr and Barker (1909) have established the avidity of coal for oxygen, and there should be a strong tendency for coal to remove oxygen from groundwater moving along the coal. Furthermore, there is sufficient pyrite in the calcareous underclay in contact with coal No. 5 near St. David to furnish enough sulphuric acid to have removed the calcium carbonate from the upper part had oxidation taken place. The structure and the characters of this coal are not different from those of the coals that overlie leached underclays and should allow an equally free movement of underground waters. It seems likely, therefore, that water has not been excluded from the underclays beneath the St. David coal, but rather that circulating waters were deprived of oxygen, so that sulphuric acid was not formed from the pyrite. Thus, the hypothesis that groundwater has moved along coals as channelways, has oxidized pyrite, has liberated sulphuric acid, and has leached the carbonates from the upper part of the underclays is not convincing.

Stout's (1923, p. 545) hypothesis is embodied in the following statement quoted from his conclusions:

> "The clays, therefore, appear to have formed in swamps during periods of decay of plant life, and to be made up primarily of terrigenous sediments, modified by plant action and other agencies, and secondarily of insoluble portions of the plant ash. There was no break in the plant life during the formation of clay and coal but a change in the degree of decomposition or decay.
>
> "It seems as reasonable to believe that there were periods of complete decay of the plant remains as to believe that there were periods of preservation when the vegetable matter was preserved as coal. If coals represent the latter condition, then clays mark the former."

Stout's concept is not clear, particularly as an explanation of the composition and distinctive properties of the underclays.

A few writers have suggested that the underclays were deposited by the wind, but the stratification and the lenses of sand in some underclays are more suggestive of accumulation in water. The particle size characteristics of the underclays are unlike those of generally recognized eolian sediments. The flattened clay pellets are also suggestive of deposition in water. Pennsylvanian land surfaces have been pictured as areas overgrown with dense coal-forming vegetation, and barren areas furnishing vast quantities of dust to form underclays do not fit into the picture. For these reasons and because there is no positive evidence for an eolian origin, such an explanation does not seem satisfactory.

Some writers have considered the underclays as aqueous sediments, which have undergone no post-depositional alteration but have been subjected to purification during or prior to accumulation. Thus, Hodson (1927) states that underclays were altered by chemical agents present in the swampy environment in which they were deposited, and Lovejoy

(1923) considers that the material of the underclays was transported through swampy areas and there purified.

## SEDIMENTARY HISTORY SUGGESTED BY MINERAL COMPOSITION AND TEXTURE

The mineralogical and textural data favor an aqueous environment of deposition for the underclays. They do not however indicate whether it was marine or nonmarine. Weller (1930) has presented evidence for a nonmarine environment, and this general conclusion is favored by the presence of fresh-water limestones with many underclays.

Most of the underclays do not appear to have been altered, after accumulation and before burial, by any processes similar to those forming modern soils. Other underclays have been affected only very slightly by such processes. The question may be raised whether or not the underclays are composed of such resistant material that weathering processes could operate for a considerable interval of time without producing any notable effects. Investigations of weathering processes, particularly in relation to loess (Bray, Grim, and Leighton) in Illinois which contains much illite, have indicated that illite is easily altered by weathering processes. This indicates, therefore, at least when illite is the important constituent, that the underclay would readily show the results of weathering processes. The data from the silicates other than the clay minerals provide the same indication.

The question arises as to whether the underclays have undergone mineralogical changes due to processes other than those of surface alteration. It is conceivable that the illitic underclays may have been deposited as montmorillonitic mud in an environment containing alkalies. Because of its adsorptive ability, potash and other alkalies could have been taken up by the montmorillonite, and later, probably after burial, a change to illite could have taken place. Likewise, it is conceivable that the kaolinitic underclays may have been deposited as montmorillonitic mud in a relatively alkali-free environment. After burial alteration to illite would be prevented by the absence of potash and other alkalies, and a change to kaolinite may be postulated. A mixture of illite and kaolinite would develop from material containing limited amounts of potash. From this postulate, it would follow that the kaolinitic underclays accumulated in a nonmarine or brackish-water environment and that the illitic ones were deposited in a marine environment, unless it is considered that the potash infiltrated into the material after deposition. The uniform composition and widespread distribution of the illitic clays and the absence of a satisfactory source of the potash are arguments against post-accumulation infiltration of alkalies.

An alternative under this postulate is the deposition of all underclays as kaolinitic material. Because of the absence of potash the earlier underclays would not be altered, whereas the younger ones, upon obtaining accessible potash, would later be changed to illite. The low adsorptive ability of kaolinite and the pronounced difference in make-up of kaolinite and illite make this suggestion improbable.

It cannot be considered that the kaolinitic clays were originally deposited as illite because change from illite to kaolinite requires the removal of potash and magnesia, as in weathering processes. It has previously been pointed out that such alteration did not occur.

No evidence for such post-depositional changes in the clay mineral composition of the underclays can be presented, but strong evidence is available against it. The kaolinitic clays occasionally contain thin definite horizons of clay composed of a distinctive member (Grim and Bradley) of the illite group interlaminated in the underclay. It is not likely that a mineralogical change would have affected all the material except that in a very thin definite bed, or that it would have caused a different change to take place in such a thin bed. The absence of uniform orientation of the clay mineral flakes in the illitic clays is evidence also against post-burial alteration. It is believed [5] that when illite develops from another material under the compacting weight of overlying material the tendency is for all flakes to form with their long axes normal to the compacting weight. In other words, the development of illite after burial would probably cause the rock to be laminated. It may be argued that the illite developed after accumulation but before burial. However, unless one accepts the transformation as taking place without any compacting force, which is very unlikely, an orientation of clay minerals would probably take place.

As indicated, certain of the conceivable mineralogical changes imply a fresh-water environment for some underclays and a brackish-water environment for others. This is not in agreement with the occurrence of fresh-water limestones in both kaolinitic and illitic underclays.

The alternative concept and the one favored by the authors is that the underclays have suffered no mineralogical rearrangement—*i.e.*, the material accumulated with its present clay mineral constitution. Under this interpretation, the source area supplied material of different character in early Pennsylvanian time when kaolinite clays were deposited and in later Pennsylvanian time when illitic material accumulated, unless the material came from different source areas. At the present time kaolinite is a weathering product formed in quantities under certain climatic conditions. This suggests a different climatic environment in the source area

[5] This subject will be gone into in greater detail in a later paper by Grim.

in early and later Pennsylvanian time. However, in a kaolinite-producing environment one would expect to find kaolinite at the top of the weathering residuum grading downward into less altered material which might be illitic. Consequently, the lower Pennsylvanian underclays may have been derived from the upper part of the residuum, and the upper Pennsylvanian underclays from the lower part of the residuum. Examples of underclays containing kaolinite are known beneath coals younger than coal No. 2, but they are believed to be local.

The most distinctive characteristic of the underclays and the one which must be accounted for in any satisfactory explanation of their sedimentary history is their content of many small slickensided fracture surfaces. Weller (1931) and Wanless [6] have suggested that the deposition of the underclays was followed by an interval of nondeposition and exposure. The vertical distribution of calcite, organic material, and limonite also indicates this conclusion, although the clay mineral data show that the exposure was not of sufficient duration for the alteration of the clay mineral constituents. Since the slickensided surfaces do not continue into overlying or underlying beds, and it has been shown that there was no post-burial mineralogical change of the clay, this character must have developed before burial. In view of these considerations, the most satisfactory explanation is that the slickensided surfaces are due to drying out and shrinking of the material in the brief interval during which it was exposed. A contributing factor may have been the abundant organic material distributed through the clay. Much of this material is carbonaceous, showing that the original accumulation of clay contained fragments of wood. Decomposition of this material on exposure to the atmosphere, following the drying out of the clay, may have produced small cavities which were closed by slippage of the clay along small fracture surfaces. This factor is suggested by the relatively increased abundance of organic material along many of the fractured surfaces.

## WORKS TO WHICH REFERENCE IS MADE

Allen, V. T. (1930) *Petrography of the weathered zones of glacial deposits,* Geol. Soc. Am., Bull., vol. 41, p. 85.

——— (1932) *Petrographic and mineralogic study of the underclays of Illinois coals,* Am. Cer. Soc., Jour., vol. 15, p. 564-573.

Bray, R. H., (1930) *Base-exchange capacity studies on certain soil types in Illinois,* Am. Soil Survey Assoc., Bull. 11, p. 161-168.

———, Grim, R. E., and Kerr, P. F. (1935) *Application of clay mineral technique to Illinois clay and shale,* Geol. Soc. Am., Bull., vol. 46, p. 1909-1926.

———, ———, and Leighton, M. M.: *The weathering of loess in Illinois,* Manuscript.

[6] Personal communication

Endell, K., Hofmann, U., and Maegdefrau, E. (1935) *Concerning the raw clay material of the German cement industry,* Zement, vol. 24, p. 625-631.

Endell, U. (1910) Jahrb. f. Min. Bull. 31, p. 1-54.

Everhart, J. O. (1936) *The mineralogical composition of some refractory clays,* Paper presented at the 1936 meeting of the Am. Cer. Soc.

Glass, J. J. (1934) *Standardization of index liquids,* Am. Mineral., vol. 19, p. 459-465.

Grim, R. E. (1934) *Petrology of the Pennsylvanian shales and noncalcareous underclays associated with Illinois coals,* Am. Cer. Soc., Bull., vol. 14, p. 113-119, 129-134, 170-176.

———, and Bradley, W. F. (1938) *A unique clay from the Goose Lake* Illinois, *area,* Am. Cer. Soc., Jour., In press.

———, and Bray, R. H. (1936) *The constitution of various ceramic clays,* Am. Cer. Soc., Jour., vol. 19, p. 307-315.

———, ———, and Bradley, W. F. (1937) *The mica in argillaceous sediments,* Am. Mineral., vol. 22, p. 813-829.

Hodson, F. (1927) *Origin of bedded Pennsylvanian fireclays in the United States,* Am. Cer. Soc., Jour., vol. 10, p. 721-746.

Hopkins, T. C. (1901) *Origin of coal measure fireclays,* Am. Geol., vol. 28, p. 47-51.

Lang, A. (1920) Jahrb. Hallischen Verbandes, vol. 2, p. 65-92.

Leighton, M. M., and MacClintock, P. (1930) *The weathered zones of the drift sheets of Illinois,* Jour. Geol., vol. 39, p. 28-53.

Lovejoy, E. (1923) *Theory of origin of coal measure fireclay,* Am. Cer. Soc., Jour., vol. 8, p. 756-761.

Parr, S. W. and Barker, P. (1909) *The occluded gases in coal,* Univ. of Ill. Exp. Sta., Bull. 32, p. 27.

Stahl, A. (1912) *The distribution of kaolin deposits in Germany,* Archiv. für Lagerstätten K. Preussischen Geol. Landesanstalt. Heft. 12.

Stout, W. C. (1923) *Coal formation clays of Ohio,* Ohio Geol. Survey, 4th ser., Bull. 26.

Stremme, H. (1912) *The chemistry of kaolins,* Fortsch. d. Min. Kryst. u. Pet., vol. 2, p. 111-121.

Wanless, H. R. (1931) *Pennsylvanian cycles in western Illinois,* Ill. State Geol. Survey, Bull. 60, p. 179-193.

———, and Weller, J. M. (1932) *Correlation and extent of Pennsylvanian cyclothems,* Geol. Soc. Am., Bull., vol. 43, p. 1003-1016.

Weiss, F. (1910) *Occurrence and origin of the kaolin of the East Thuringia Bunter sand basin,* Zeit. prakt. Geol., vol. 18, p. 353.

Weller, J. M. (1930) *Cyclical sedimentation of the Pennsylvanian period and its significance,* Jour. Geol., vol. 38, p. 97-135.

Wheeler, H. A. (1896) *Clay deposits,* Missouri Geol. Survey, vol. 11.

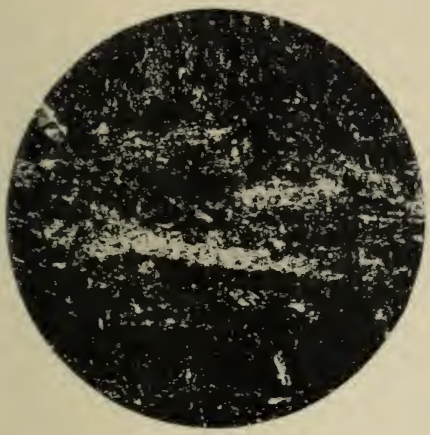
Worthen, A. H. (1866) *Geology of Illinois,* Geol. Survey of Illinois, vol. 1, p. 59.

Illinois State Geological Survey, Urbana, Illinois; St. Louis University, St. Louis, Missouri.
Manuscript received by the Secretary of the Society, April 18, 1938.
Presented before the Society, December 27, 1935.
Published with the permission of the Chief, Illinois State Geological Survey, Urbana, Ill.

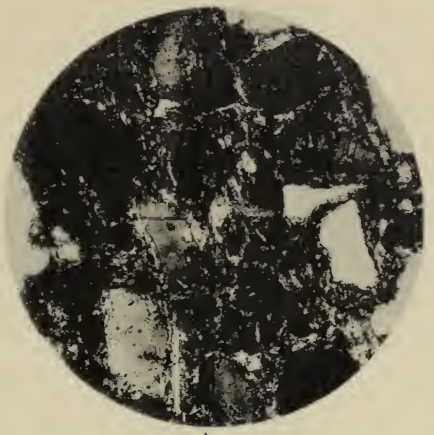
## EXPLANATION OF PLATES 1 AND 2

PLATE 1.—PHOTOMICROGRAPHS OF UNDERCLAYS

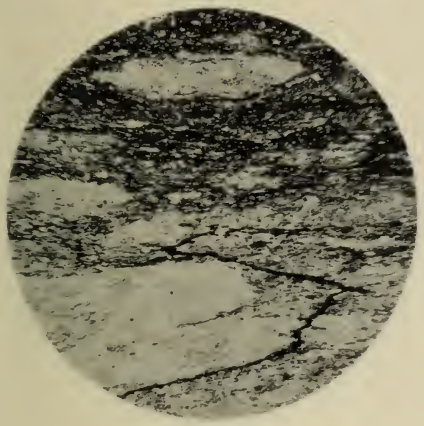
(a) Areas in matrix showing uniformity of orientation of clay mineral particles; lower Pottsville underclay, Goose Lake area, Grundy County. X-nicols. X300.
(b) Uniformly oriented matrix particles enclosing grains of quartz; lower Pottsville underclay, Goose Lake area, Grundy County. X-nicols. X300.
(c) "Blue band" clay parting in coal No. 6, Franklin County, Illinois. Light areas are flattened pellets. Dark line is rootlet. X46.
(d) Pellet structure in underclay below coal No. 2, near Ripley, Illinois. Dark area is carbonaceous material. X35.
(e) Partially "eaten into" nodule of calcite; underclay below coal No. 8, near Fithian, Vermilion County. X20.
(f) Nodule of calcite with central nucleus of matrix material; underclay below coal No. 8, near Fithian, Vermilion County. X30.



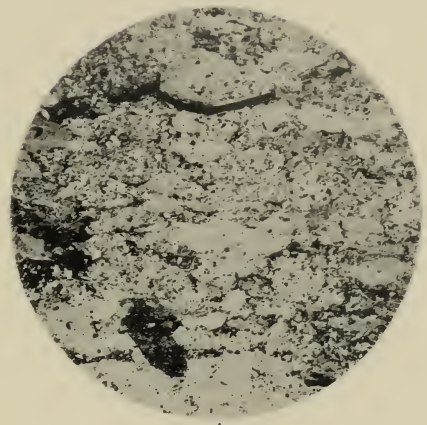
a



b

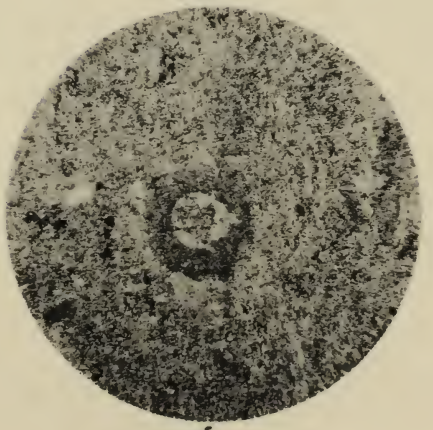


c



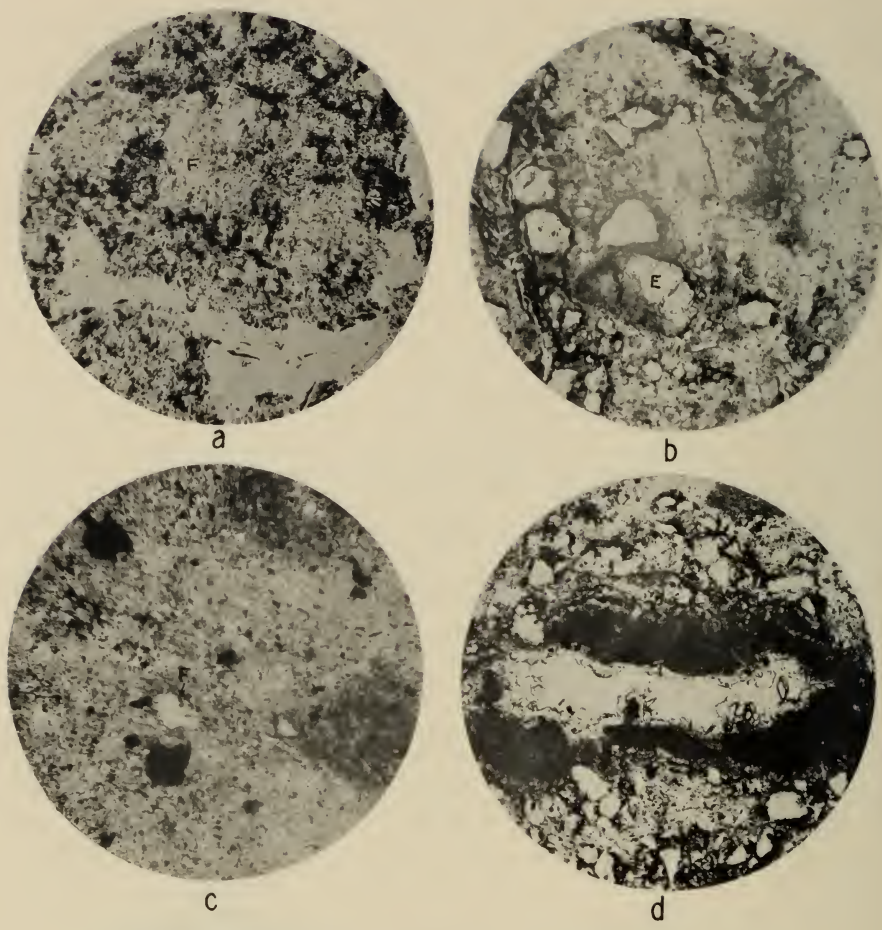
d

e



f

PHOTOMICROGRAPHS OF UNDERCLAYS




PHOTOMICROGRAPHS OF GUMBOTILS AND UNDERCLAYS

PLATE 2.—PHOTOMICROGRAPHS OF GUMBOTILS AND UNDERCLAYS

(a) Feldspar in Kansan gumbotil altered *in situ* to montmorillonitic material. Boundary is so irregular that it is difficult to draw a dividing line between clay mineral and feldspar. (F) is a remnant of the unaltered feldspar. Fairfield, Iowa. X80.

(b) Epidote (E) altered to montmorillonitic material in Illinoian gumbotil. Original outline discernible. Speck of epidote enclosed by the clay mineral. Illinois Central R. R. cut near Salem, Illinois. X46.

(c) Fresh andesine feldspar (F) in underclay half an inch below coal No. 7. Boundary sharp. Chillicothe, Illinois. X80.

(d) Underclay 5 feet below coal No. 6. Orient No. 1 Mine, West Frankfort, Illinois. Secondary calcite crystals fill former cavity near center. X46.